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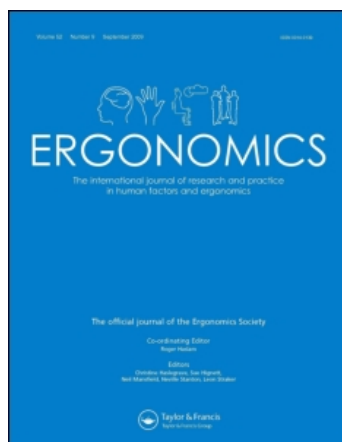
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Effect of block weight on work demands and physical workload during masonry work

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The effect of block weight on work demands and physical workload was determined for masons who laid sandstone building blocks over the course of a full work day. Three groups of five sandstone block masons participated. Each group worked with a different block weight: 11 kg, 14 kg or 16 kg. Productivity and durations of tasks and activities were assessed through real time observations at the work site. Energetic workload was also assessed through monitoring the heart rate and oxygen consumption at the work site. Spinal load of the low back was estimated by calculating the cumulated elastic energy stored in the lumbar spine using durations of activities and previous data on corresponding compression forces. Block weight had no effect on productivity, duration or frequency of tasks and activities, energetic workload or cumulative spinal load. Working with any of the block weights exceeded exposure guidelines for work demands and physical workload. This implies that, regardless of block weight in the range of 11 to 16 kg, mechanical lifting equipment or devices to adjust work height should be implemented to substantially lower the risk of low back injuries.

Keywords: Effect study; Manual materials handling; Physical workload; Low back; Construction work

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1. Introduction

Masons who lay large sandstone blocks are engaged in building and renovating houses, offices and industrial complexes using blocks weighing from 6 kg to more than 48 kg (Van Der Molen *et al.* 2004b). Laying blocks involves a high physical workload and is associated with low back disorders among masons. Jäger *et al.* (1991) reported that an increase in block mass leads to an increase in the moment and compression force at the low back of 20 Nm and 1 kN, respectively, per 5 kg block mass. Latza *et al.* (2000) found an increased risk of low back pain prevalence ratio (PR = 2.6) for workers who lay large sandstone blocks (7–10 kg) for at least 2 h per shift compared with workers who do not engage in such work. Stürmer *et al.* (1997) found that working as a bricklayer for more than 10 years increased the likelihood of low back disorders by 2.3 times (95% CI 1.2 to 4.5) compared to other construction workers. The 12-month prevalence of low back complaints among Dutch masons who laid sandstone blocks was 39% (Arbouw 2003).

Lifting devices designed for the workplaces of masons are recommended to reduce physical workload and low back complaints in the longer term (Luttmann *et al.* 1991, Vink *et al.* 2002, Van Der Molen *et al.* 2004a, Luijsterburg *et al.* 2005). The physical nature of masonry work (Anton *et al.* 2005) or barriers to behavioural change (Van Der Molen *et al.* 2005), however, hinder implementation and use of such engineering controls. Manual handling of large blocks, therefore, still occurs at many work sites, which suggests that it may be useful to ask whether there is an optimal block weight that would meet acceptable work demands and physical workload.

To answer this question, a combined field and laboratory study was performed to establish the effects of block weight on work demands and on energetic and biomechanical workload in a real world setting. Combinations of measurements (observation and direct measurement) for assessing the physical workload are needed to minimize the risks of bias that might result from relying on a single measurement approach (Van Der Beek *et al.* 2005). Exposure assessments over full work days are needed, because changes in workload caused by one ergonomic measure (e.g. reduced block weight) may differ within and between jobs of workers within a team (Burdorf *et al.* 2005, Paquet *et al.* 2005, Buchholz *et al.* 1996). Moreover, this approach enables the stakeholders who will be involved in implementing the recommendations of the study to discuss and consider the optimal strategy to reduce risks for low back pain caused by handling the large blocks manually (Dempsey and Mathiassen 2006).

The objectives of this study were to establish the effects of different block weights (11, 14 and 16 kg) on work demands and physical work load during a full work day, operationalized respectively as duration of the tasks and activities and productivity, and energetic workload and cumulative spinal load of the low back.

2. Methods

2.1. Participants and blocks

In total, 13 experienced Dutch masons who laid large blocks participated voluntarily in the study, after giving their informed consent. The masons were recruited from

companies contacted by the researchers. Company names were retrieved from the employer's organization of the masonry trade or the telephone book.

The inclusion criteria for participation were three-fold. First, each mason must have been employed in the construction industry with block laying as their main task for at least 6 months. Second, each masonry site had to be approved as an example of a frequently occurring project with usual specifications for the walls to be built and with standard work tasks, materials, tools and equipment. This approval had to be given by a technical construction consultancy. Third, each mason had to work a normal working day with the same block weight and preferably the same dimensions of block on the day the observations and measurements were performed.

Three block weights of sandstone building blocks were selected: 11 kg; 14 kg; and 16 kg. These three types of blocks are the most frequently used in the Netherlands. The 13 masons were divided into three groups, each group working with a different block weight. Two masons participated twice, for block weights 11 kg and 16 kg. The three groups of five masons did not differ in age, body height or body weight. The means of age, stature and body weight of the groups working with 11 kg, 14 kg and 16 kg blocks were 38 (SD 8), 37 (SD 16), and 33 (SD 6) years, 183 (SD 10), 187 (SD 12), 187 (SD 8) cm and 87 (SD 11), 97 (SD 20) and 86 (SD 8) kg, respectively.

Two different block sizes were observed for each block weight. For the 11 kg blocks the dimensions were: $297 \times 150 \times 148$ mm over 4 d for four masons; $297 \times 150 \times 148$ mm over a half day and $297 \times 214 \times 98$ mm over a half day for one mason. For the 14 kg blocks the dimensions were: $437 \times 100 \times 198$ mm over 4 d for four masons; $437 \times 100 \times 198$ mm over a half day and $437 \times 67 \times 298$ over a half day for one mason. For the 16 kg blocks the dimensions were: $297 \times 214 \times 148$ mm over 3 d for three masons; $297 \times 150 \times 198$ mm over 2 d for two masons.

2.2. Durations and frequencies of tasks and activities

Systematic observations of the physical work demands at the work site were performed by means of a real-time hierarchical task analysis using a renewed version of Task Recording and Analysis on Computer (TRAC system; Frings-Dresen and Kuijer 1995), called PalmTRAC (Yucat, Driebergen, the Netherlands). An observer assessed the duration and frequencies of all tasks, the activities performed during these tasks and the objects being handled for a full work day in each of the three weight conditions of the blocks (figure 1). The following variables and categories within variables were observed in real time:

- Task (block laying, preparation, sizing blocks, finishing seams, consultation or micro pauses, cleaning, breaks, manual transport, mechanical transport and 'other' tasks).
- Activity (standing, walking, sitting, climbing or kneeling, lifting of block below knee level, lowering of block below knee level, lifting of block between knee and shoulder level, lowering of block between knee and shoulder level, lifting of block above shoulder level, lowering of block from above shoulder level, preparation of glue or mortar, application of glue or mortar).
- Object handled weighing more than 4 kg (e.g. blocks or scaffolding elements).

Two observers were involved who had been trained in real-time observation with the help of a video on block-laying. The mean intraclass correlation coefficient, as a measure



Figure 1. Field measurements of block mason building a wall consisting of 11 kg sandstone blocks.

for inter-rater reliability, was good: 0.87 (SD 0.09). The intraclass correlation coefficients varied from 0.71 (95% CI 0.00–0.97) to 0.99 (95% CI 0.89–1.00).

2.3. Productivity

The number of the blocks laid during a work day was measured by observation of the block-laying task; the total number of times that the activity ‘lowering blocks’ was selected during a work day is similar to the productivity of the amount of blocks handled. The productivity (m^2) was calculated by multiplying the numbers of blocks laid by their frontal area (height \times width).

2.4. Energetic workload

To quantify the energetic workload, heart rate (HR) (beats/min) during the tasks and work day and oxygen uptake (VO_2) (ml/min per kg) during the block-laying task were determined. The mean HR of each minute was recorded using a Polar Vantage NV (Polar Electro Oy, Kempele, Finland). Data from the task analysis and HR were automatically linked and synchronized by the PalmTRAC software, based on the time both measurements started and the sampling rate of the Polar HR monitor, to obtain the mean HR during the full work day and the mean HR for the most physically demanding tasks for each participant. Next, the percentage HR reserve (%HRR) was calculated for each individual by means of HRwork (measured during task execution), HRrest (lowest mean value of all frames of 3 min that were calculated during ‘quiet’ sitting in the first morning break of about 20 min) and HRmax (calculated as

220 minus age in years), using the following equation (Karvonen *et al.* 1957, Wu and Wang 2002):

$$\%HRR = (HR_{work} - HR_{rest}) / (HR_{max} - HR_{rest}) \times 100\%.$$

VO₂ (ml/min per kg) was measured breath by breath using a portable analyser (Cosmed K4 b2, Cosmed, Italy) over at least 24 min of block laying in the morning and, where possible, in the afternoon. The first and last 2 min of the measurement were not included to correct for non-block-laying activities because the worker was switching between the activities 'connection with the VO₂ analyser' and 'block laying'. Where there were two measurements for one worker, the average VO₂ was calculated.

2.5. Cumulative spinal load on the low back

The cumulative effect of compression forces on the lumbar spine during a full work day was estimated. For any observed combination of task, activity, working height and type of object, a compression force was determined on the basis of the peak compression forces that had been established in a laboratory experiment with nine experienced block masons (Faber *et al.* 2006, Van Dieën *et al.* 2006). For each worker observed, the sequence and duration of activities, as assessed by the observers, and the corresponding peak compression force for each activity, as assessed in the laboratory, were used to construct a time series of compression forces as input for a biomechanical model that calculated the amount of elastic energy stored in the lumbar spine during a full work day (Van Dieën and Toussaint 1997).

2.6. Data analysis

The mean number of blocks laid, durations and frequencies of tasks and activities, %HRR, VO₂ and the estimated amount of elastic energy stored in the lumbar spine were all calculated for each group of five workers (i.e. for the blocks of weight 11, 14 and 16 kg). The effect of block weight on each of these outcome measures was tested using the non-parametric Kruskal-Wallis test. For all tests, a significance level of 5% was used ($p < 0.05$).

3. Results

The results for all the outcome measures are summarized in table 1.

3.1. Effect of block weight on production

The mean numbers of blocks laid in the wall per full work day for the 11, 14 and 16 kg block weights were 294 (SD 107), 261 (SD 74) and 240 (SD 78), respectively (table 1). Half of all blocks were handled with one hand. Block weight had no significant effect on the number of blocks laid ($p = 0.57$). However, the number of square metres laid per work day did differ between the 11 and 14 kg blocks ($p = 0.02$) and between the 14 and 16 kg blocks ($p = 0.02$). Working with 14 kg blocks resulted in covering the largest frontal area, on average 24.0 m² (table 1).

Table 1. Outcome variables productivity, duration of tasks, duration of lifting activities, % heart rate reserve, oxygen consumption (VO₂) and cumulative spinal load over a regular work day for block masons (n = 15) while working with sandstone building blocks of 11, 14 or 16 kg.

	11 kg block (n = 5)				14 kg block (n = 5)				16 kg block (n = 5)			
	Mean	SD	min	max	Mean	SD	min	max	Mean	SD	min	max
Productivity												
Blocks (number) per work day	294	107	150	426	261	74	193	370	240	78	149	339
Frontal area (m ²) per work day*	12.7	5.0	5.7	18.7	24.0	8.0	16.7	33.2	11.5	2.3	8.7	14.9
Duration of tasks (min)												
Full work day	439	18	407	451	432	15	407	448	431	10	418	441
Work preparation	98	38	62	142	80	22	50	106	84	14	66	103
Block laying	155	36	100	198	143	30	102	172	150	22	128	180
Duration of lifting activities (min)												
Lifting below knee	13	5	8	19	13	7	5	21	20	6	11	28
Lowering below knee	7	3	3	10	3	2	2	5	4	3	2	8
Lifting knee – shoulder**	13	6	7	20	15	1	14	18	8	4	4	13
Lowering knee – shoulder	10	8	3	20	12	3	8	16	13	6	4	20
Lifting above shoulder	0	0	0	0	0	0	0	0	0	0	0	0
Lowering from above shoulder	3	3	0	7	3	2	1	6	1	2	0	4
% Heart rate reserve												
Full work day	28	11	18	43	26	6	16	31	21	5	16	28
Work preparation	31	12	21	49	27	5	19	31	23	5	18	31
Block laying	34	14	20	54	34	7	23	43	26	5	20	33
VO₂ (ml/kg⁻¹ per min)												
Block laying	16.5	3.7	11.2	21.7	14.7	4.3	10.3	19.5	14.5	3.2	10.6	18.8
Cumulative spinal load												
Elastic energy stored in lumbar spine (J)	5.1	0.7	4.3	5.8	6.8	2.3	4.7	10.6	6.7	3.6	3.6	12.6

*Significantly different ($p = 0.02$).

**Significantly different ($p = 0.04$).

3.2. Effect of block weight on durations and frequencies of tasks and activities

Work days of block masons lasted well over 7 h (table 1). The task of 'block laying' lasted about 2.5 h (33 to 35% of the working time). As second longest task, 'work preparation' lasted about 1.5 h (19 to 22% of the working time). Block weight had no effect on the duration of tasks or activities, except that lifting blocks of 16 kg between knee and shoulder height did not take as long as lifting blocks of 14 kg ($p = 0.04$). Moreover, as already noted in section 3.1, block weight had no effect on the total number of blocks handled during a full work day.

3.3. Effect of block weight on energetic workload

The mean %HRR of handling blocks of 11, 14 and 16 kg during a full work day was 28 (SD 11)%, 26 (SD 6)% and 21 (SD 5)%, respectively. The mean VO_2 during the task block laying was 16.5 (SD 3.7), 14.7 (SD 4.3) and 14.5 (SD 3.2) ml/min per kg for 11, 14 and 16 kg blocks, respectively. Block weight was not found to have a significant effect on the energetic workload.

3.4. Effect of block weight on cumulative spinal load

The cumulative spinal load expressed as cumulated elastic energy (J) varied among block masons between 3.6 J and 12.6 J for a full work day. The mean cumulated elastic energy for working with block weights of 11, 14 or 16 kg was 5.1 (SD 0.7), 6.8 (SD 2.3) and 6.7 (SD 3.6), respectively (table 1). Block weight was not found to have a significant effect on this, and thus neither on cumulative spinal load during a full work day.

4. Discussion

This study revealed that block weights of 11, 14 and 16 kg had no significant effect on productivity, duration or frequency of tasks and activities, energetic workload or cumulative spinal load over a full work day.

4.1. Effect of block weight on productivity

The weight of blocks had no significant effect on productivity of the number of blocks placed or on the total weight handled. At least 3234 kg (for 11 kg blocks), 3654 kg (for 14 kg blocks) and 3600 kg (for 16 kg blocks) per day was handled by the block masons, indicating high work demands for each of the manually handled block weights and an increased risk of low back complaints (Elders and Burdorf 2004). Working with 14 kg blocks resulted in more production in terms of square metres than for 11 or 16 kg blocks. However, this was not caused by the weight but by the size of the blocks. The 14 kg blocks, on average, had a greater frontal area.

4.2. Effect of block weight on work demands

Overall, a higher or lower block weight within the range of 11 to 16 kg did not result in any increase or decrease in the duration and frequency of physically demanding tasks and activities. There was only one exception to this: lifting between knee and shoulder level was of shorter duration for the 16 kg blocks than for the 14 kg blocks. This was,

however, not because of block weight but probably owing to the workplace setting. Working with 16 kg blocks was done on a scaffold, while the blocks were stacked at a maximum height of only two blocks. Therefore, more blocks were lifted below knee level instead of between knee and shoulder level.

Lifting, lowering and carrying are risk factors for low back pain (Bernard 1997, Lötters *et al.* 2003). During the task of laying blocks, lifting activities lasted 46 min per day for all three block types. The estimated time of working with one or two hands below knee level was on average 20 (for 11 kg blocks), 16 (for 14 kg blocks) and 24 (for 16 kg blocks) min. The observed durations of lifting and deep bending were indeed risk factors for the incidence of back complaints. Based on the Dutch criterion document for assessment of the work-relatedness of non-specific low back pain (Lötters *et al.* 2003, Kuiper *et al.* 2005), the observed durations of lifting and deep bending while working with the three blocks weights seem to be associated with an increased risk of work-related low back pain.

4.3. Effect of block weight on energetic workload

Anton *et al.* (2005) also studied the effect of block weight (11.8 and 16.3 kg) on energetic workload during a 'block-laying' task. Comparing HRs in their study with those in the present study, their results indicate that HRs for the block weight of 11.8 kg were about 10% higher than for the 11 kg block in the present study and 2% lower for the 16.3 kg block weight than for the 16 kg block in the present study. In contrast to the present study, other studies have found that block weight, varying between 3.5 and 20.5 kg, had a positive effect on energetic workload (Asfour *et al.* 1983, De Looze *et al.* 1994). There are two factors that may explain this. First, the energetic workloads in the Asfour *et al.* (1983) and De Looze *et al.* (1994) studies were measured at activity level and not at task level. At task level, it is likely that a less strenuous activity, such as standing or walking without handling a load, follows the more strenuous activity of lifting blocks. As a consequence, the calculated average HR at task level will be lower. Second, Lee and Chen (1995) found that lifting frequency has a more profound effect on the energetic work load than load weight per se. The frequencies of lifting in the studies by Asfour *et al.* (1983) and De Looze *et al.* (1994) varied between three and nine times per min. Compared to these two studies, the frequency in the present study was relatively low during the task of laying blocks: less than two lifts per min. Thus, there may be an interaction between load mass and lifting frequency with regard to the energetic workload during lifting.

The mean %HRR of masons in the present study over a full work day was 28% (for 11 kg), 26% (for 14 kg) and 21% (for 16 kg). According to Wu and Wang's (2002) equation, a maximum acceptable work duration based on the energetic workload would be 6.8 h, 7.5 h and 9.5 h for 11, 14 and 16 kg blocks, respectively, while in the present study work days of 7.2 to 7.3 h were observed. Thus, the mean maximum acceptable work duration according to Wu and Wang (2002) was not (or was only slightly) exceeded. For a few individual block masons, however, the maximum acceptable work duration was exceeded.

4.4. Effect of block weight on cumulative spinal load

The average amount of elastic energy stored in the lumbar spine during a mason's work day was high and indicates that the risk of incidence of back injury was considerable for all three weights of blocks within the range of 11 to 16 kg. As indicated by Van Dieën and Toussaint (1997), the duration of lifting activities found in this study would increase the

probability of low back injury. On the basis of their energy model, it has been calculated that working with the 11, 14 and 16 kg block weights indicates a risk to 73%, 81% and 76% of the workers, respectively. Because of the limitations of the model (since the strength values of the spine are based principally on cadaver materials of relatively old persons), prediction of an absolute risk value is not possible (Van Dieën and Toussaint 1997). Use of this model comparatively shows that the block masons in the present study are at higher risk for low back injuries with all the three block weights than are workers who perform other manual handling jobs, such as refuse collectors handling two-wheeled containers, who have 7 % risk (Kuijer *et al.* 2002), or gypsum bricklayers handling 18 kg bricks, who have 35% risk (Grouwstra *et al.* 2005). In the comparison with refuse collectors, the difference is most likely a result of the lower compression forces when pulling and pushing than when lifting (Schibye *et al.* 2001). The difference in risk compared to gypsum bricklayers is probably because of the use of a static biomechanical model in the study of Grouwstra *et al.* (2005) rather than the dynamic biomechanical model used in the present study, resulting in considerably lower compression forces despite the higher load handled by the gypsum bricklayers.

4.5. Implications for practice

Working with each of the three block weights exceeded ergonomic criteria for work demands (Lötters *et al.* 2003) and cumulative spinal load (Van Dieën and Toussaint 1997). Therefore, an intervention aimed at reducing the weight of blocks within the range of 11 to 16 kg would not seem to be effective in reducing the risk of musculoskeletal complaints among block masons. Thus, investing in mechanical lifting equipment (Marras *et al.* 2000) or devices to adjust working height (Marras *et al.* 2000, Van Der Molen *et al.* 2004a, Luijsterburg *et al.* 2005) seems to be more appropriate as a preventive ergonomic measure. It is, however, possible that a study that used a greater range of block weights could reveal still lower block weights to be advantageous in reducing the risk of musculoskeletal complaints.

4.6. Strengths and limitations of the study

This combined field and laboratory study allowed the combination of precise measurements of work demands over a full work day with estimates of energetic and cumulative spinal load (Waters *et al.* 2006). Moreover, this study took into account the block weights (and types) that are currently the most used in Dutch masonry work, thereby increasing the generalizability of the results.

A limitation of this study was the lack of power to detect small effect sizes. It is preferable to perform a power analysis, in order to calculate the required sample size, but an estimation was not possible due to insufficient information from comparable studies about the standard deviations of the main outcome measures. Therefore, based on a study by Hoozemans *et al.* (2001) of variation in activities, it was expected that the observation of five workers for a full working day should have been sufficient to obtain a relatively precise estimate of the frequency and duration of tasks and activities. This assumption was – afterwards – reflected in the low standard deviations of the most important outcome measures with coefficients of variation below 50% (see table 1). The question remains whether a measurement strategy aimed at including more workers but with shorter observation periods could have resulted in a gain in statistical power. Post-hoc analysis on one of the outcome measures relevant for the incidence of low back

complaints (duration of lifting blocks below knee level) revealed that it should be possible to detect an effect size of 0.84 on this continuous variable at a two-tailed significance 5% level with a power of 80%. Increasing the number of participants to ten workers per block would have made it possible to find even smaller effect sizes.

Observation of a whole working day is the most desirable time frame and appeared to be feasible when pilot testing. However, there are no data about the reliability of the observation method that was used over a full day analysis. The inter-rater reliability on the basis of video analysis was very high. Generally, the intra-rater reliability is higher than the inter-rater reliability, so in view of the high inter-rater reliability it is assumed that there was a high intra-rater reliability.

The masons were not randomly assigned to a particular block weight, because the aim was to observe masons in a normal field setting. In construction work, block type and weight is always prescribed by the specification of the general contractor and, therefore, block weight could not randomly be assigned to the masons. Sampling bias, however, is not likely because all masons were experienced in block laying and were working regularly with various dimensions and weight of blocks, including the blocks used in this study. Moreover, the inclusion criteria for this study ensured that the measurements were made at sites representative of commonly occurring projects with the usual specifications for the wall to be built and with standard work tasks, materials, tools and equipment.

5. Conclusions

Block weight, varying between 11 and 16 kg, had no effect on production for the number of blocks placed and total weight handled, duration and frequency of tasks and activities, energetic workload and cumulative spinal load over a full work day. Working with each block exceeded existing ergonomic criteria for work demands and biomechanical workload. This implies that, regardless of block weight in the range of 11 to 16 kg, mechanical lifting equipment or devices to adjust working height should be implemented to substantially lower the risk of low back injury.

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